Characterization of CdMnTe Planar Nuclear Detectors Grown by Vertical Bridgman Technique

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***Abstract*–Cadmium manganese telluride (CdMnTe) crystals are expected to be homogenous in structure due to the segregation coefficient of Mn in CdTe, which is about 1.0. This could translate in the growth of large-volume CdMnTe crystals free of defects that currently limit X-ray and gamma-ray detection efficiencies. The present characterization experiments show results on CdMnTe planar detectors grown by the vertical Bridgman technique. The CdMnTe crystal used in the experiments was mostly free of tellurium inclusions and high-angle grain boundaries. We recorded an energy resolution of 9.2% FWHM for the 59.5-keV gamma-peak of 241Am for the planar detector. We also resolved peaks at energies below the 59.5-keV peak.**

I. Introduction

THE ability to operate at room temperature without cryogenic cooling is a major advantage for field-portable nuclear detection systems. The absence of cooling units translates to lower costs, portability, compact instruments, and ease of deployment in remote and wide-area applications. Commercially available room-temperature semiconductor nuclear detectors are often made with cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe or CZT). High-resolution applications in gamma spectroscopy, medical imaging and astrophysics have employed CZT detectors [1]–[4]. However, CZT is prone to defects associated with Te inclusions, dislocations, sub-grain boundaries, and precipitates [5]–[8]. These defects degrade charge-carrier transport within the detector matrix, thus resulting in a lowering of the detector efficiency. The segregation coefficient of Mn in CdTe matrix is ~1.0 and that of Zn in CdTe is 1.35 [9]-[10]. Thus, cadmium manganese telluride (CdMnTe or CMT) grown by Bridgman technique is expected to have better crystal compositional uniformity. This could result in less Te inclusions, dislocations, and sub-grain boundaries, which in turn could lead to a higher yield of detector-grade crystals with less defects and an associated higher energy resolution for fabricated devices. CMT ingots with a larger detector-grade volume will also lower the cost of detectors.

We have conducted crystal-growth experimentation to systematically develop CMT [5], [11]–[17]. For this study we grew $Cd_{1-x}Mn_xTe$ with x = 5% [5]. The crystals were synthesized from 6N purity CdTe bought from 5N Plus, 99.9998% pure Mn and 6N purity Te from Alfa Aesar. Conically tipped ampoules coated with carbon were used. In our first growth run we got a low-resistivity crystal on the order of 10^5 Ω-cm containing Te inclusions with diameters of 2 to 28 μm, but very few grain boundaries [5], [13]. The Te inclusions and grain boundaries were greatly reduced in a second growth run, and a detector-grade CMT was obtained in the third growth [17]. The detector-grade CMT had a resistivity on the order of 10^{10} Ω-cm and electron mobility-lifetime (μτ) products of 1.7 x 10^{-3} cm^2/V. An energy resolution of 7.5% FWHM for the 662-keV peak of ^{137}Cs was obtained for a Frisch grid CMT detector at 2900 V [17]. In this paper, we present our recent results of the characterization of a CMT planar detector.

II. Experiment

The CMT sample was prepared as described in [19]. A 6.6 x 3.6 x 2.9 mm^3 was cut from as-grown CMT ingot (grown by Bridgman technique) using a diamond impregnated wire. The wafer was mechanically polished on silicon-carbide abrasive papers, successively using 600-grit, 800-grit, 1000-grit, and 1200-grit papers. Fine polishing was accomplished by using alumina (Al_2O_3) powders. Sizes from 3.0 μm to 0.1 μm of Al_2O_3 were successively used to get mirror-shine surfaces. After drying the sample with compressed nitrogen gas, gold contacts were deposited on opposite sides of the wafer by pipetting drops of gold chloride solution on the surfaces.

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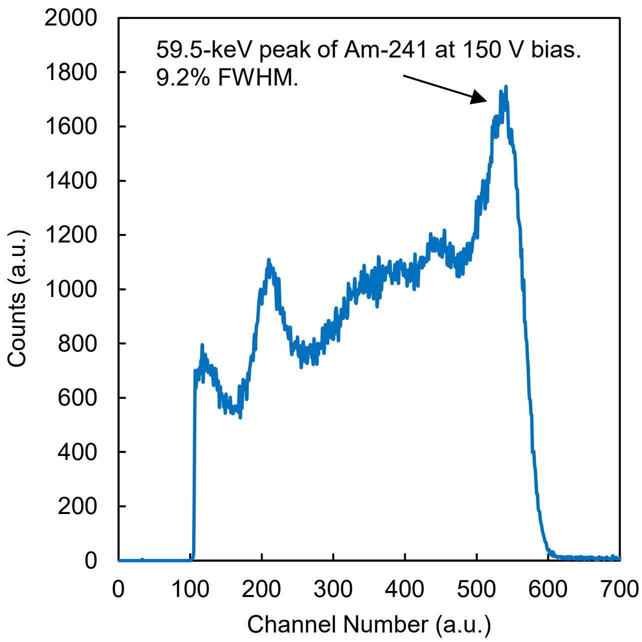

Fig. 1. Response of the CdMnTe planar detector to the 59.5-keV gamma line of ^{241}Am at a bias of 150 V. Energy resolution: 9.2% FWHM.

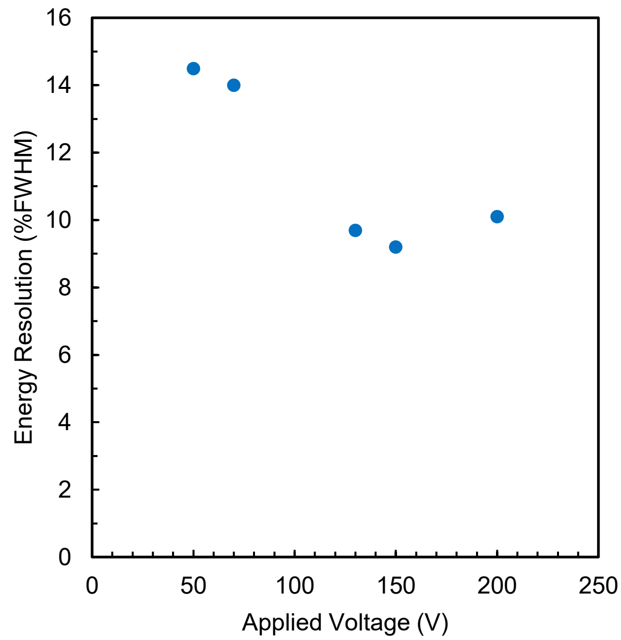

Fig. 2. Energy resolution of the CdMnTe planar detector for the 59.5-keV gamma line of ^{241}Am at different bias voltages.

The tip of a felt paper was used to absorb excess gold chloride solution after it reacted with the wafer surface. A customized box made of aluminum and equipped with a Keithley Picoammeter/Voltage Source was used for the current-voltage (I-V) measurements.

The resolution of the CMT detector was measured by mounting it on a standard eV Products (now Kromek) sample holder made of brass. A sealed ^{241}Am source was placed on a beryllium window fitted in the sample holder. The signal generated by the detector was passed through a pre-amplifier and amplifier to a multichannel analyzer and computer.

III. Results

A resistivity of 2.7 x 10^{10} Ω-cm was obtained for the CMT detector using the slope of the plot from the I-V measurements [19]. The response of the detector to a ^{241}Am radiation source is shown in Fig. 1. The detector resolution for the 59.5-keV gamma of ^{241}Am is 9.2% FWHM at 150 V bias. A 9.5% FWHM was obtained at 130 V bias [19]. The energy resolutions at different bias voltages are shown in Fig. 2. The optimum energy resolution for this CdMnTe detector was obtained at a bias of 150 V.

IV. Summary

We presented recent results for a planar detector fabricated from a CMT ingot grown by the Bridgman technique. The development of the CMT took three systematic growth runs that initially focused on reducing Te inclusions, dislocations, and sub-grain boundary networks that often plague CdTe-based semiconductors. These problems and related defects were greatly reduced by the second growth run [5], [13]; and detector-grade CMT was obtained in the third growth run [17]. One of the reasons for the quick success is the compositional uniformity exhibited by CdMnTe due to the segregation coefficient of Mn in CdTe matrix being ~1.0. Crystal growth expertise and knowledge from studies on optimization of the ampoule carbon-coating in CZT [5], where the optimum coating was found to be 0.2 μm, also contributed to our success. Future studies will focus on chemical passivation of CMT surfaces.

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